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D. Y. Richardson
J. W. Sinko
Stanford Research Institute
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PACKET RADIO MODEL FOR SYSTEM SECURITY

Abstract:

A simulation developed to aid in investigating the security of packet radio networks is described. The simulation currently can model slotted and unslotted Aloha and carrier sense access modes, finite numbers of terminals, repeaters and stations (with fixed routing), and various buffer sizes at each component. To validate the system an unslotted Aloha system with ten terminals and "infinite" buffers at the terminals was modeled; the throughput surprisingly exceeded the maximum theoretically predicted for an infinite number of terminals with no buffers, surpassing the .3 level.

The difference in throughput is due primarily to two assumptions in the simulation model that are not in the theoretical model: buffers in the terminals and a finite number of terminals. When a terminal is blocked and a long retransmission delay is used, several packets build up in the buffer before the terminal can transmit again. However, when it finally does transmit, it is likely that no other terminal will block the transmission, so all the packets in the buffer will be successfully sent in quick succession. Thus the whole mode of operating is somewhat different than the theoretical model.

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I INTRODUCTION

At this time, no firm decisions have been, or can be, made regarding the network protocol features, e.g., access mode, acknowledgment schemes, and routing. One of the many necessary inputs needed for making these decisions is the effect of network protocol on system security. Two system security issues, it is felt, can best be investigated by using a simulation model. The first of these issues is spoofing, in which the enemy disables the system by interfering with the radio signals that control packet flows; e.g., replaying packet headers or jamming the busy tone of a busy-tone system. Spoofing implies that the enemy can disable the system with much less power than would be required to brute-force jam the communications channel. The second issue to be investigated with the simulation model is physical security; how does the system perform when one or more repeaters are removed from the system - does the routing procedure allow the system to function under these conditions?

The simulation is also being used to aid in the propagation and noise measurement program. To perform these measurements a channel test facility is being fabricated. The facility is organized around mini-computers and the hardware is directly affected by system features such as access mode and number of channels. It is desirable to make the test facility resemble components of a future operational packet radio system as closely as is practicable.

Many analytical studies have been made which will contribute to the decision of which network protocol will be used. The throughput of slotted and unslotted Aloha systems has been analyzed in publications concerning the Aloha System. Throughputs for several variations of carrier sense systems have been found in Temporary Packet Radio Notes (TPRN) 24, 37, and 51. Reservation systems have been discussed in TPRN 51 and 68 and ARPA Satellite System Notes (ASS) 2 and 20. TPRN 7, 37, 45, and 68 analyze the delays that packets experience. TPRN 45 discusses two channel systems (slotted, unslotted and carrier sense). All of these results are restricted in that they apply only to a system with no

I. INTRODUCTION

repeaters and assume a Poisson source, inferring a very large number of terminals. Very little analysis has been done on systems with repeaters (TPRN 23 and 30).

An appreciable amount of work has been devoted to analytic studies of packet radio. While much insight has been gained in understanding the tradeoffs involved in network protocols, many questions still remain unanswered: the behavior of a network with repeaters, the effect of acknowledgment schemes and the effect of a finite number of terminals. TPRN 67 reports the results obtained by using a simulation model to examine throughput and delays of various access schemes. The model keeps track of each packet generated, but still assumes a Poisson source and no repeaters.

The model being used to examine spoofing and physical security can also be used to examine some of the system protocol issues. So far the model has been used to examine systems with a finite number of terminals, multiple repeater systems and the carrier sense hidden terminal problem (in which some terminals cannot hear other terminals, yet all terminals can block transmissions to the station). The effect of different numbers of buffers at the terminals has also been examined. The simulation models are being used to supplement the understanding (gained from analytical results) of packet radio systems so that the experimental packet transmission and receiving system can incorporate features that will be found in an operational packet radio system.

II SUMMARY OF PARAMETERS AND FEATURES PRESENTLY IMPLEMENTED IN THE SIMULATION

1. The number of terminals, stations, repeaters can be varied to the limits of the capacity of the computer on which the simulation is run.
2. Network configuration (linking) can be designated.
3. Different access schemes (slotted, carrier sense, unslotted) can be used.
4. The capacity of buffers at terminals, stations, and repeaters is a parameter.
5. The average time between packet retransmissions or between senses (carrier sense) for each of terminals, stations, and repeaters is a parameter.
6. The distribution of packet generation times at the terminals can be varied.
7. The percentage of traffic from a terminal destined for other terminals as opposed to being destined to the station itself is a parameter.
8. The number and distribution of packets returned from the station to the sending terminal (or other terminals) can be varied.
9. The average amount of packet processing delay at a station before return packet(s) is(are) transmitted is a parameter.
10. Amount of waiting time for acknowledgment before a retransmission decision is a parameter.
11. For carrier sense interference occurs when two packets are transmitted within a certain fraction of the packet transmission time of each other. This fraction represents propagation and detection delays and is a parameter in the simulation.

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III SAMPLE RESULTS

In order to test the veracity of the simulation model a number of runs are being made for various access modes. The results of these runs will be reported in a separate note. As an example of the kind of results the model yields, an interesting Aloha system phenomenon that has been observed using the model will be discussed.

The simulation was set up for a configuration of ten terminals and a single station (no repeaters) and an unslotted Aloha access mode was tested. Unlimited buffer sizes were assumed at terminals (the maximum number of packets stored was 10 and 26 for throughputs of 0.2 and 0.3 respectively). Each terminal had new packets being generated at random times, the interarrival distribution being exponential. The protocol used allows a terminal to transmit successive packets in its buffer immediately after an acknowledgment is received for the preceding packet. If no acknowledgment is received the terminal must wait a random length of time before retransmitting the packet (retransmission delay). The delay is uniformly distributed between 0 and 2k where k is the average retransmission delay. Packets must be transmitted in the order in which they are generated so that a packet can never arrive at the station out of sequence. Acknowledgments are assumed to be on a separate channel which is reliable. It takes 1/10 of a packet length to return the acknowledgment. All transmissions are from the terminals to the station.

The simulation outputs the average packet delay from the time it is generated at the terminal until it is successfully received at the station: the packet delay includes waiting at the transmit queue, transmission times and retransmission delays. The packet delays are output for various packet generation rates at the terminals. For each input rate, the actual packet throughput is calculated where throughput is defined as the number of successfully terminated packets as a fraction of the number of packets for 100% channel utilization. Figure 1 displays these outputs for the example.

The results obtained from the simulation were somewhat surprising. Throughput increased continuously with increasing retransmission delays (although the rate of increase was low for very long retransmission

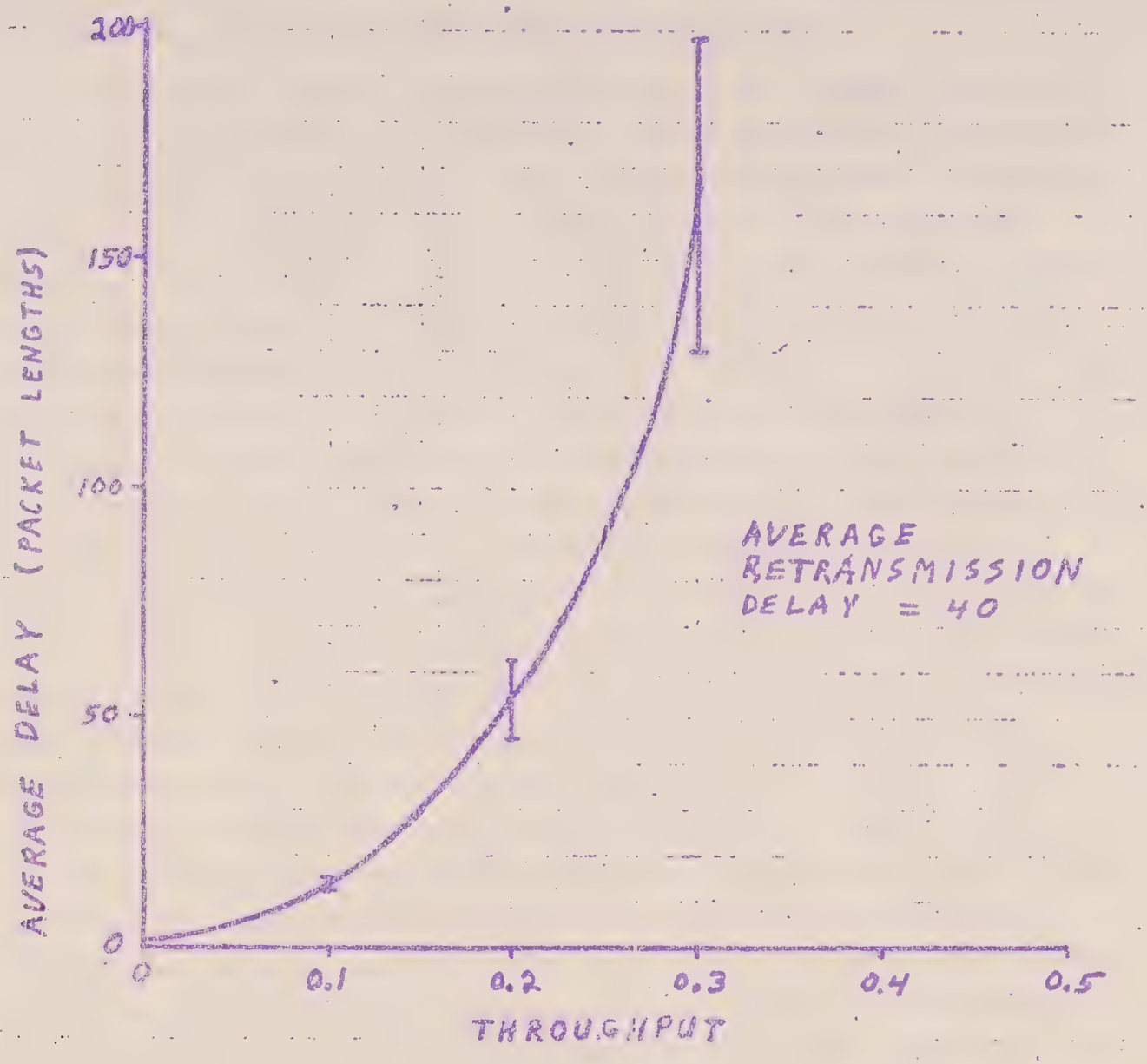


Figure 1. Throughput and average delay for one way transmission from ten terminals with unlimited buffers to a station. The vertical lines are 90% confidence intervals for the simulation output.

delays). Throughputs in excess of 0.3 were obtained for oneway transmission from the terminals to the station with k = 40 (see Figure 1). This is in sharp contrast with theoretical analysis which predicts a maximum throughput of 1/e (0.18). The wide discrepancy between the results predicted by the model and by theoretical studies led to a more detailed examination of how the modeled system operates.

First, sample timeline analyses were performed. Figure 2 shows an example of the packets in the channel as a function of time. The originating terminal is denoted by the first number on each packet. The second number is arbitrarily assigned to distinguish packets from the same terminal. Note that there are several occurrences of a number of packets from a single terminal entering the channel in quick succession. This phenomenon is responsible for the much higher throughput by the model than predicted by theoretical analysis. The difference in throughput is due primarily to two assumptions in the simulation model that are not in the theoretical model: buffers in the terminals and a finite number of terminals (or more specifically, the number of terminals being much smaller than the average retransmission delay measured in packet lengths). When a terminal is blocked, the long retransmission delay usually causes several packets to build up in the buffer before the terminal can transmit again. However, when it finally does transmit, it is likely that no other terminal will block the transmission, so all the packets in the buffer will be successfully sent in quick succession. Thus the whole mode of operation is somewhat different than the theoretical model. This mode would be ideally suited for digitized voice and intercomputer communication networks and would be of less use in the data communication networks using keyboard input devices. With no buffers at the terminals throughput decreased to the level predicted by theoretical analysis even with ten terminals.

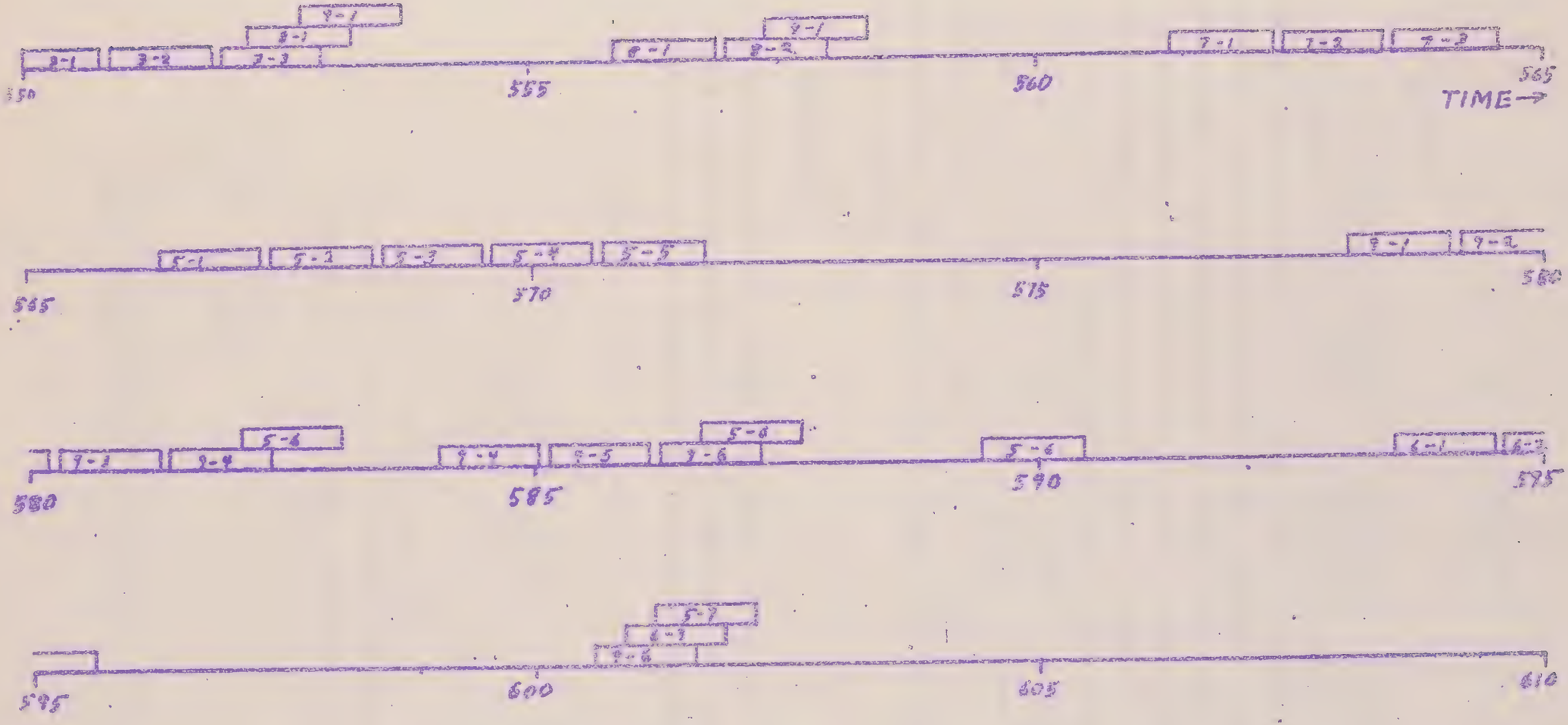


Figure 2: A timeline display of packets. The first number in each packet corresponds to the originating terminal. The second number is assigned to sequentially identify packets from a given terminal.

IV THE SIMULATION

A. Approach

A simulation of a packet radio network on a packet by packet basis is obviously a queuing problem. Simulation of queuing problems in a general purpose scientific language, such as Fortran or Algol, or in assembly language is difficult from the programmer's standpoint because events must be sequenced in order of their occurrence. When there are a large number of possible events, queuing programs in these languages become complex, lengthy and it is usually difficult to incorporate changes in protocol of the simulated system. These problems led to the decision to write the packet radio simulation in GPSS, a language specifically designed for the simulation of queuing systems. Sequencing of events is performed automatically by the processor, freeing the user from this tedious task. The program is quite compact (due to the highly macro nature of GPSS).

B. Description

Each packet flows through the network according to a prescribed routing scheme. Each node, terminal, repeater, or station, is assigned a unique network node number for identification purposes, see Figure 3.

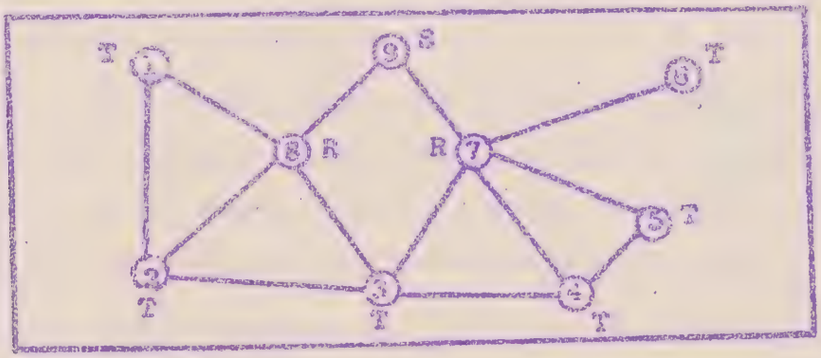


Figure 3: Packet Radio Sample Network.

S → Station
R → Repeater
T → Terminal
— → Link
○ → Node
The numbers within the nodes are the "Network Node Numbers"

To understand basic operations the model can be conceptually separated into three major categories:

(a) Generation of packets at the terminals

(b) Packet transmissions on the various channels according to a given channel access scheme and the subsequent determination of interference and appropriate retransmissions

(c) Selecting the next hop destination for each packet and resubmitting the packet to part (b) for transmission if necessary.

An overview flowchart of the program is shown in Figure 4.

In part (a) each packet that is generated has 5 parameters associated with it:

(1) Network node number of the current location of the packet

(2) Network node number of the originating node of the packet

(3) Network node number of the "next hop" or immediate destination of the packet

(4) Network node number of the final destination of the packet

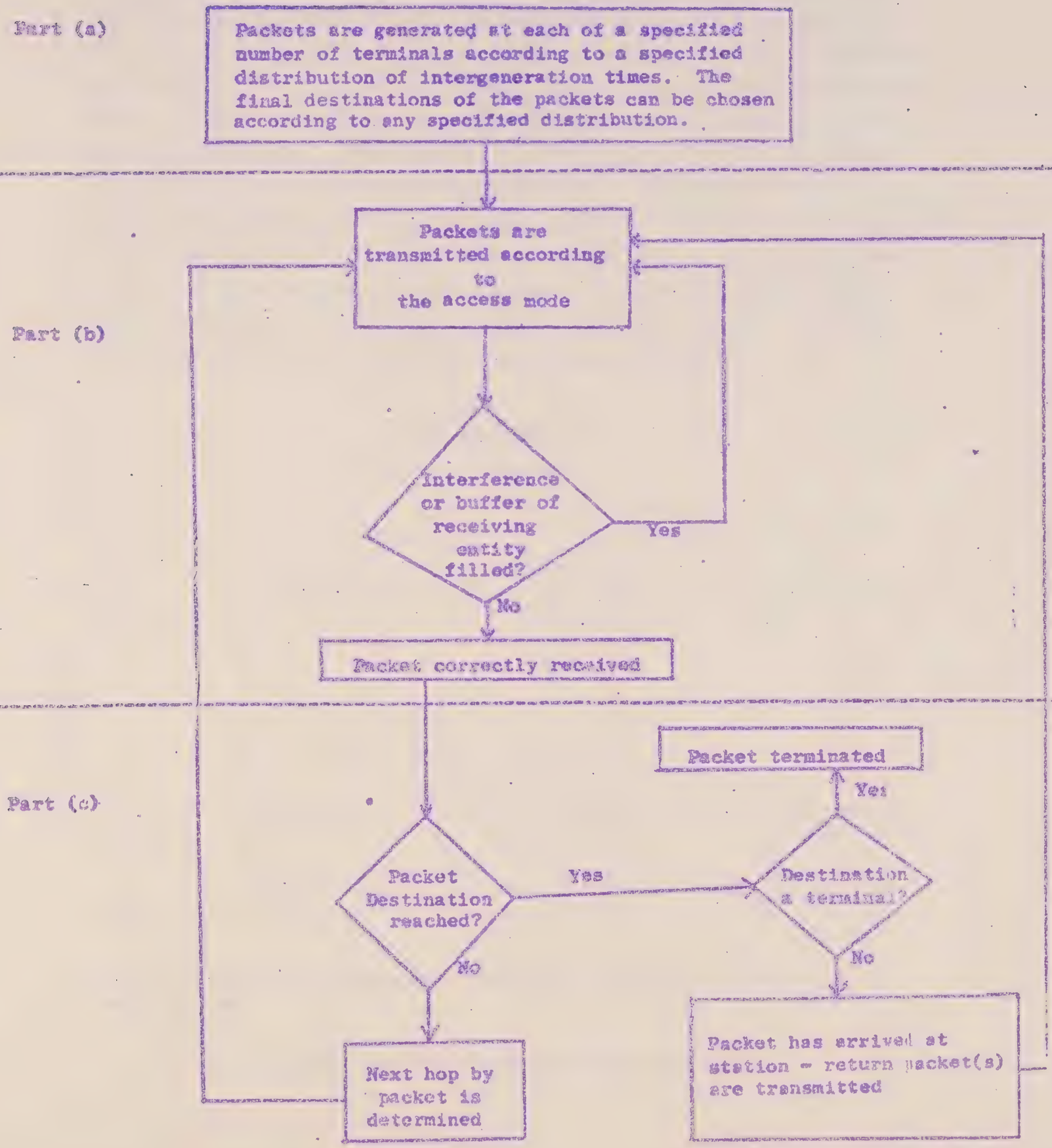
(5) Interference flag.

Packets are released independently from the terminals according to a specified distribution(s) (e.g., exponential) of packet intergeneration times. As soon as the packet leaves a given terminal, another enters the terminal and is assigned an expected departure time.

Immediately after entering the terminal parameters (1), (2), (3), and (4) are designated for the packet. Parameter (2) is designated the same as parameter (1) since the current location and origin of the packet are the same at this time. Parameter (4), the final destination, may be assigned arbitrarily. Parameter (3) is assigned according to a routing matrix.

Figure 4

OVERVIEW FLOW CHART OF PACKET RADIO
BY MAJOR MODEL FUNCTIONS


Part (a)
Packets are generated at each of a specified number of terminals according to a specified distribution of intergeneration times. The final destinations of the packets can be chosen according to any specified distribution.
Part (b)
Packets are transmitted according to the access mode
Interference or buffer of receiving entity filled?
Yes
No
Packet correctly received
Part (c)
Packet terminated
Yes
Destination a terminal?
Packet Destination reached?
Yes
No
No
Next hop by packet is determined
Packet has arrived at station - return packet(s) are transmitted

The a_{ij} elements of the routing matrix represent the immediate destination [parameter (3)] of a packet currently located at the node i [parameter (1)] with final destination node j [parameter (4)]. The lowest rows and columns of the routing matrix represent terminals. Under this scheme there is a fixed routing of the packet in the network. Knowing parameter (1) and parameter (4), parameter (3) can be properly designated by element a_{ij} where i equals the value of parameter (1) and j equals the value of parameter (4). The a_{ij} elements are input by the user at the start of the program. For example, a fixed routing plan for the sample network of Figure 3 would be that all terminals send packets only to the station and terminals 1, 2, 3 would send packets to the station via repeater 8 while terminals 4, 5, 6 would send packets to the station via repeater 7. All packets from the station would be sent to a terminal by the reverse routing procedure in response to a packet from that terminal. Figure 5 represents this routing matrix for the network of Figure 3.

FINAL DESTINATION

CURRENT LOCATION		Terminals						Repeaters		Station
		1	2	3	4	5	6	7	8	9
Terminals	1									8
	2									8
	3									8
	4									7
	5									7
	6									7
Repeaters	7				4	5	6			9
	8	1	2	3						9
Station	9	8	8	8	7	7	7			

The blank entries in this table are unnecessary for the prescribed routing plan.

Figure 5: Sample Routing Matrix for Figure 3 Network

After the packets are assigned parameters (1) - (4), they enter the conceptual area described by part (b) above. Each packet is queued in the buffer of the particular terminal at which the packet resides. For each node in the network the first packets in the respective queues are allowed to enter transmit status. No other packet is allowed this status until the first packet in that queue has reached the immediate destination of parameter (3) and an acknowledgment is assumed received. Acknowledgments are assumed to be on a separate channel which is reliable. The packet in transmit status is actually transmitted according to the access scheme which has been set in the program. (At present slotted, unslotted, and carrier sense access schemes have been implemented.) Each packet is checked both at the beginning and end of the transmit period as to whether interference with other packets will occur or did occur during that period. Interference is determined by checking the value of a variable which is based on the interference matrix. The b_{ij} element indicates (by a 1 = yes or 0 = no) if the ith node transmitter can be heard by the jth node receiver. These b_{ij} elements are input by the user at the start of the program. Figure 6 shows the interference matrix for the network of Figure 3. The interference variable for a given packet is defined as the following:

$$V_{p3} = \sum_{i=1}^{n} b_{i\,p3} \cdot T_i$$

where

n = number of nodes in the network

$b_{i\,p3}$ = value of the interference matrix for the ith row and the immediate destination column [parameter (3)]

T_i = transmit value (1 = yes, 0 = no) for ith node.

RECEIVING COMPONENT

TRANSMITTING COMPONENT		Terminals						Repeaters		Station
		1	2	3	4	5	6	7	8	9
Terminals	1	1	1	0	0	0	0	0	1	0
	2	1	1	1	0	0	0	0	1	0
	3	0	1	1	1	0	0	1	1	0
	4	0	0	1	1	1	0	1	0	0
	5	0	0	0	1	1	0	1	0	0
	6	0	0	0	0	0	1	1	0	0
Repeaters	7	0	0	1	1	1	1	1	0	1
	8	1	1	1	0	0	0	0	1	1
Station	9	0	0	0	0	0	0	1	1	1

1 = Radio link

0 = No radio link

Figure 6: Interference Matrix for Figure 3 Network

If V_{P3} is greater than one (i.e., more than one packet is heard at the destination of the given packet) for a packet at the beginning or end of its transmit period, then interference occurred and parameter (5) of the packet, the interference flag, is set (1 = set, 0 = not set). At the completion of their transmissions those packets whose interference flags have been set or those packets traveling to immediate destinations whose buffers are full are not acknowledged, experience a random delay and are retransmitted. Buffer sizes can be set in the model.

In CPSS all times, without loss of generality, are designated by integers. A time unit equal to the packet transmission time is ideally suited for slotted access schemes while a time unit a fraction of the packet transmission time approximates a continuous time line for non-slotted access schemes.

Those packets whose interference flags have not been set have successfully reached their immediate destination. These packets are acknowledged and processed for the next routing decision embodied by conceptual part (c) of the model. In part (c) the immediate destination reached for each packet is tested to see if it is the same as the final destination. If these destinations are not the same then the value of parameter (1), the current packet location, is changed to that of parameter (3) and then parameter (3), the immediate destination , is set to be the element from the parameter (1) row and the parameter (4) column of the routing matrix: The packet is then placed in the new parameter (1) transmit queue and is processed as in part (b), channel transmission.

If the immediate and final destination for the packet are identical, it is determined whether the final destination is a station or whether it is a terminal. If the final destination is a terminal, current protocol of the program causes the packet to be terminated. When the final destination of the packet is the station and this destination is reached, various options are available:

(1) Packets may simply be routed to some terminal which may be specified randomly or non-randomly. (Usually packets are simply routed to the originating terminal.)

(2) The number of packets sent from station can be varied according to any specified distribution. (Note that as a trivial example of this protocol zero packets may be sent from the station.)

(3) Packets may be delayed according to any distribution for processing before protocols (1) and (2) above take effect.

For packets routed from the station parameter (4), the final destination, is chosen according to one of the mentioned protocols, parameter (1) is set to the value of the station as is parameter (2), the new packet origin, and parameter (3) is chosen by the element of the parameter (1) row and the parameter (4) column of the routing matrix. These packets

from the station are placed in the station transmit queue and each packet is treated according to part (b) of the program categories, packet transmission. Section II summarizes the currently available parameters in the simulation. Table 1 lists features which could be implemented in the future.

Table 1

LIST OF FEATURES WHICH CAN BE IMPLEMENTED
WITH ADDITIONAL EFFORT

1. Varying packet lengths
2. Fraction of packets lost
3. Adaptive routing schemes
4. Additional access modes (busy tone, reservation)
5. Acknowledgment schemes

APPENDIX

PROGRAM EXAMPLE

A simple network with an unslotted Aloha access mode is presented as a programming example. This example differs from that used to obtain the data in Figure 1 because packets are returned from the station. Included in the discussion of the example is a description of the network features including packet transmission protocols, description of both the input to the GPSS program, a flow diagram (Figure A-3), and a program listing (Figure A-4). It is to be noted that each block in the flow diagram with the accompanying description corresponds to a statement in the listing; in this manner the flow diagram provides for a listing with comments. The simulation program as evidenced by the listing is short allowing the parameters and other features to be easily manipulated. For examples of more complex networks including repeaters and for networks with other access modes the authors should be consulted.

The particular features of the example network are as follows:

(1) There are ten terminals in hearing distance of one station.

(2) All packets are routed to the station from the terminals.

(3) The packet undergoes a uniform random processing delay at the station with range from 1 to 21 packet transmission times.

(4) Two packets are returned from the station to the originating terminal for each packet received.

(5) The buffer capacities at the terminals and station are unlimited.

(6) The wait time for acknowledgment is 1/10 of the packet transmission time.

(7) The range of the uniformly distributed retransmission delay is from 0 to 80 packet transmission times for terminals and 0 to 26 packet transmission times for the station.

Figures A-1 and A-2 represent the packet flows from terminal to station and station to terminal respectively.

Common to all of the access schemes and networks is a basic set of inputs. The format at the beginning of the program listing (Figure A-4) includes the following basic inputs in sequential order:

(a) A number of functions
(b) Two matrices and respective initialization statements
(c) Variable statements
(d) Storage definition statements.

The first of the five functions is the distribution function of the packet intergeneration times at each of the terminals. For this example an exponential distribution is used. The second function assigns the final destination of the packets generated at the terminal. For the example, all packets generated at the terminals were sent to the station. Function three and function four provide the uniform random retransmission delays. Function three is the mean and function four represents one-half of the spread of the delay. These functions also allow different uniform delays for different nodes in the network. In the example there were differences in the delays for the station and terminals. For convenience in entering functions three and four, designation of the nodes in the network is done in such a manner that stations, terminals, and repeaters are respectively grouped together. Terminals always represent the lowest numbered nodes for convenience and sake of convention in conducting tests of the parameters of the packets to determine whether the final packet destination of a packet is a terminal or a station. Function five represents the packet buffer size for each of the nodes in the network.

The two matrices defined in this program are the interference matrix (matrix number one) and the routing matrix (matrix number two). The dimensions of these matrices equals the number of nodes in the network. The initialization statements set up the elements in both of these matrices. Variable one is the interference variable defined in the previous section.

Subsequent variables are simply continuations of variable one. The boolean variable following the variable statements constitutes a test for either interference or maximum buffer capacity, or both.

There is a storage definition statement for each node in the network each with a capacity of one. These storage areas represent the transmit status mentioned in the previous section. The final storage area designated "hold" is the hold area for packet generation at the terminals. Its capacity is equal to the number of terminals in the network.

Another input frequently changed in the packet flow section of the program for all access schemes is block 9 field A; this number represents the mean intergeneration time for packets of each terminal.

PACKET FLOW FROM A TERMINAL TO THE STATION

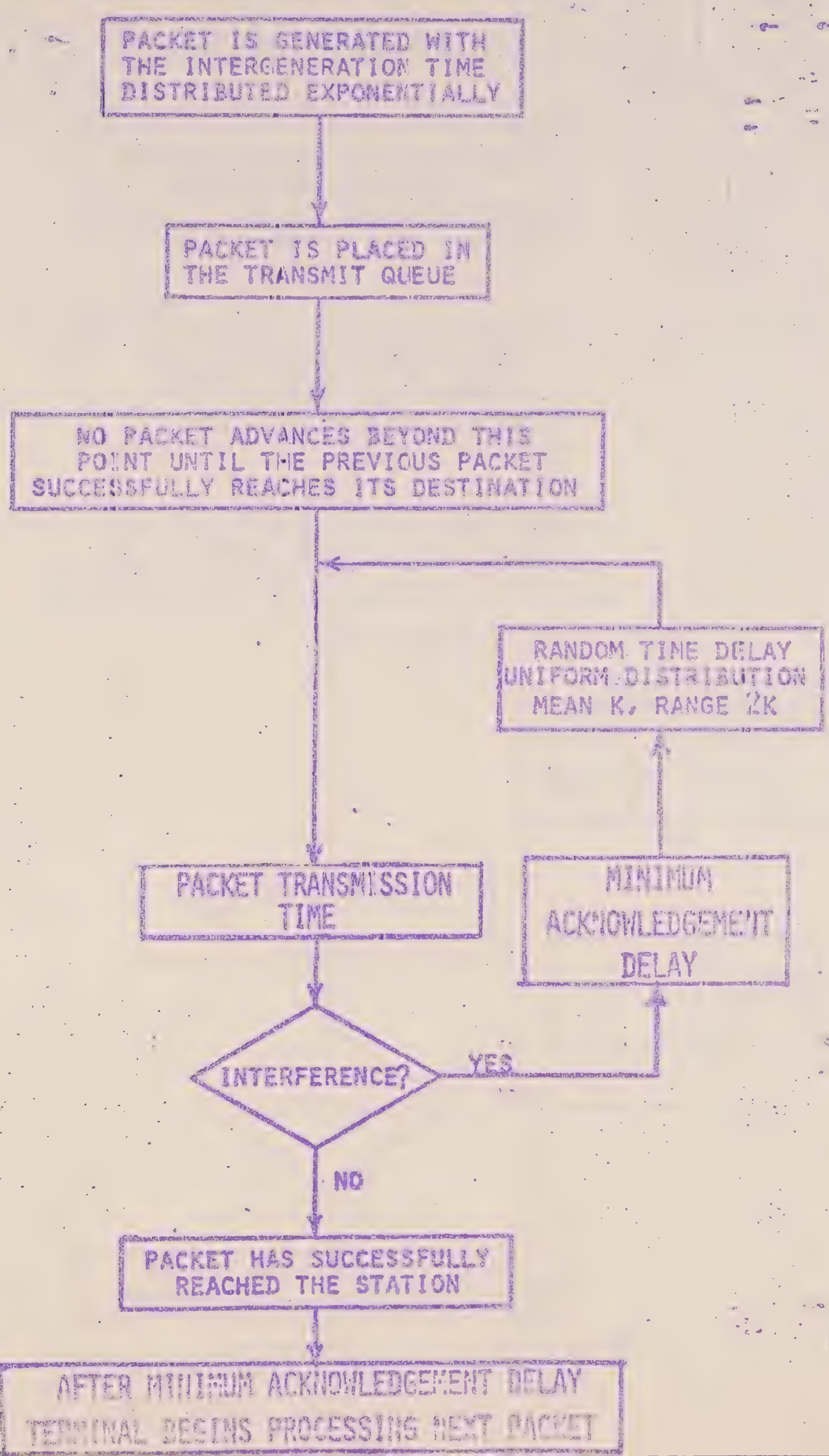

PACKET IS GENERATED WITH THE INTERGENERATION TIME DISTRIBUTED EXPONENTIALLY
PACKET IS PLACED IN THE TRANSMIT QUEUE
NO PACKET ADVANCES BEYOND THIS POINT UNTIL THE PREVIOUS PACKET SUCCESSFULLY REACHES ITS DESTINATION
RANDOM TIME DELAY UNIFORM DISTRIBUTION MEAN K, RANGE 2K
PACKET TRANSMISSION TIME
MINIMUM ACKNOWLEDGEMENT DELAY
INTERFERENCE?
YES
NO
PACKET HAS SUCCESSFULLY REACHED THE STATION
AFTER MINIMUM ACKNOWLEDGEMENT DELAY TERMINAL BEGINS PROCESSING NEXT PACKET

Figure A-2

PACKET FLOW FROM THE STATION TO A TERMINAL

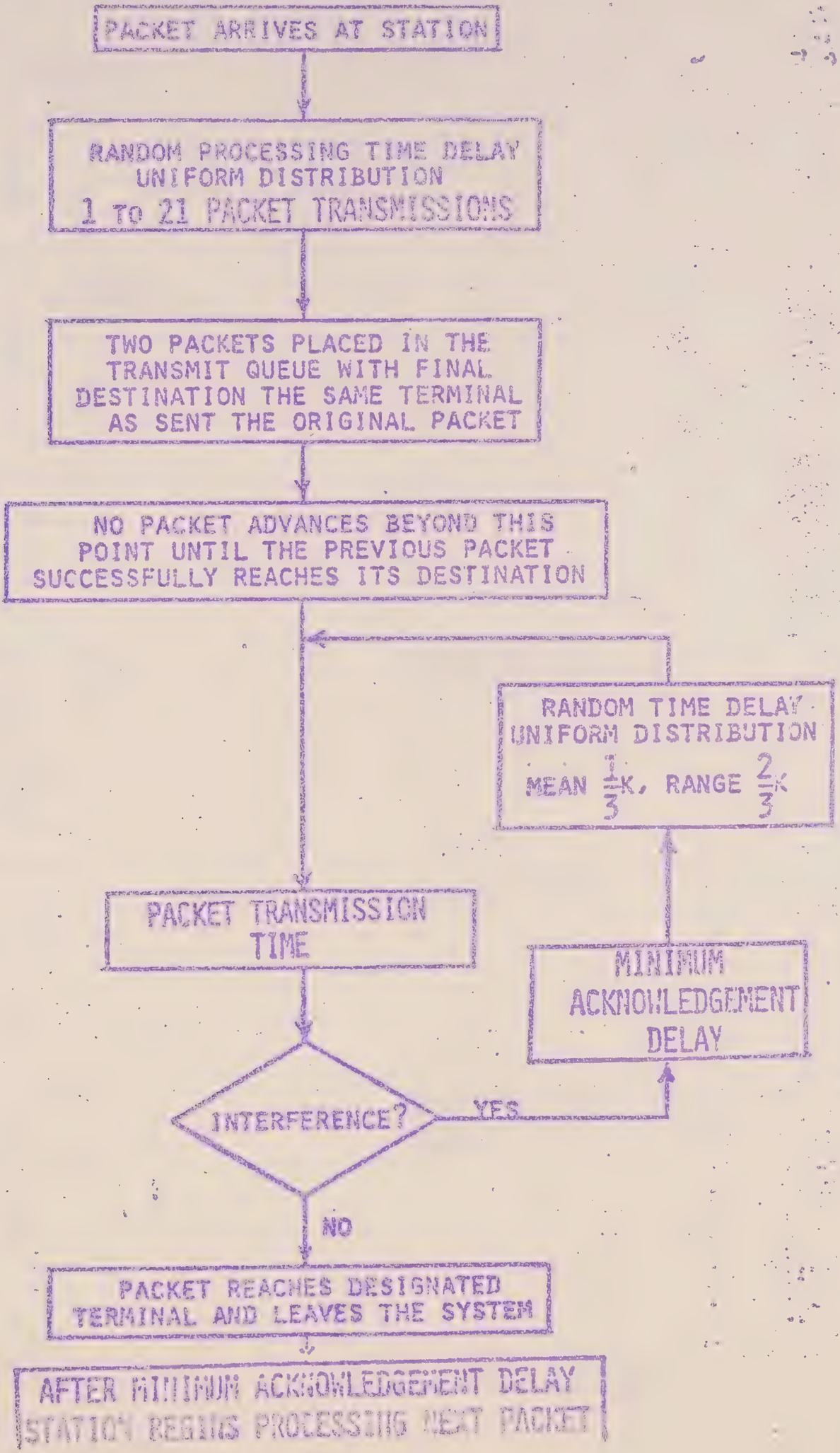
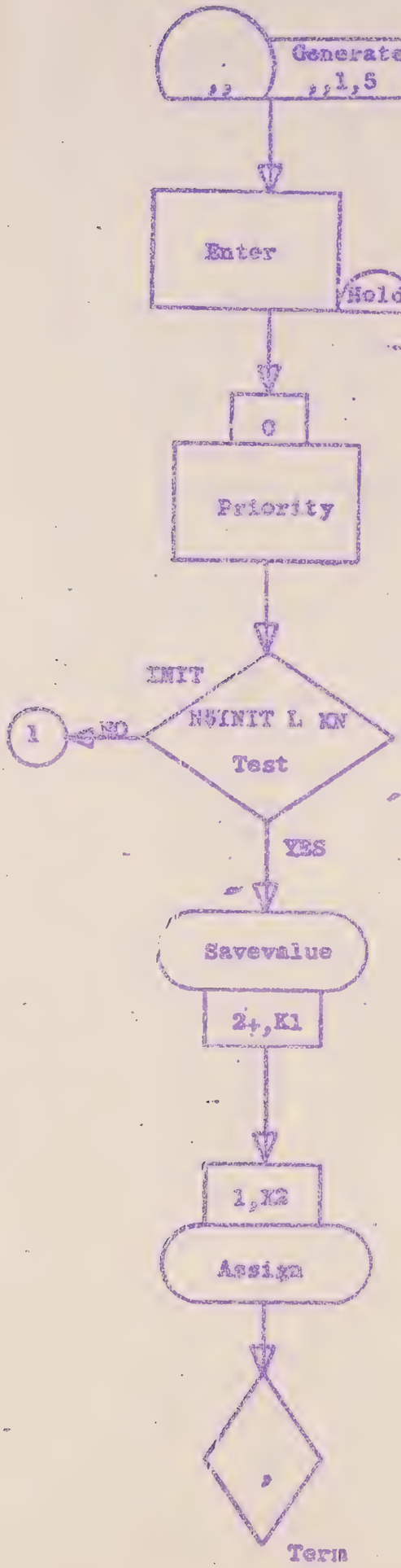

PACKET ARRIVES AT STATION
RANDOM PROCESSING TIME DELAY
UNIFORM DISTRIBUTION
1 TO 21 PACKET TRANSMISSIONS
TWO PACKETS PLACED IN THE TRANSMIT QUEUE WITH FINAL DESTINATION THE SAME TERMINAL AS SENT THE ORIGINAL PACKET
NO PACKET ADVANCES BEYOND THIS POINT UNTIL THE PREVIOUS PACKET SUCCESSFULLY REACHES ITS DESTINATION
RANDOM TIME DELAY
UNIFORM DISTRIBUTION
MEAN $\frac{1}{3}K$, RANGE $\frac{2}{3}K$
PACKET TRANSMISSION TIME
MINIMUM ACKNOWLEDGEMENT DELAY
INTERFERENCE?
YES
NO
PACKET REACHES DESIGNATED TERMINAL AND LEAVES THE SYSTEM
AFTER MINIMUM ACKNOWLEDGEMENT DELAY STATION BEGINS PROCESSING NEXT PACKET

Figure A-3

UNSLOTTED ALOHA FLOW CHART



Packets are Created

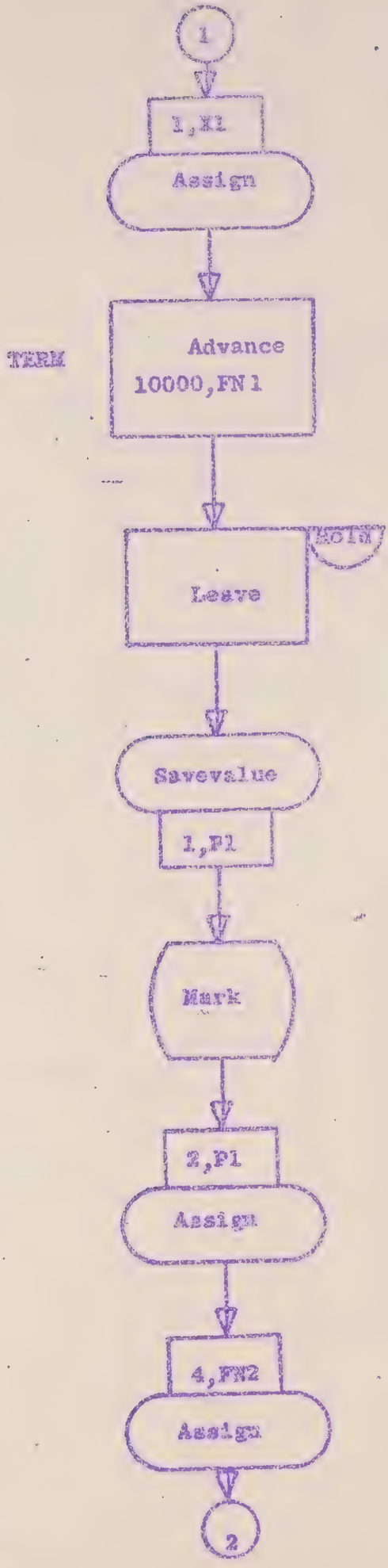
First N Packets?
N = No. of Terminals

Increment Counter

Assign to Packets First N Consecutive Integers (Node Numbers)

Transfer to Time Delay

Figure A-3 (Continued)



Assign Node Number to New Packet Equal to the Node Number of the Last Packet to Leave Hold Area

Packet Intergeneration Time

Leave Hold Storage

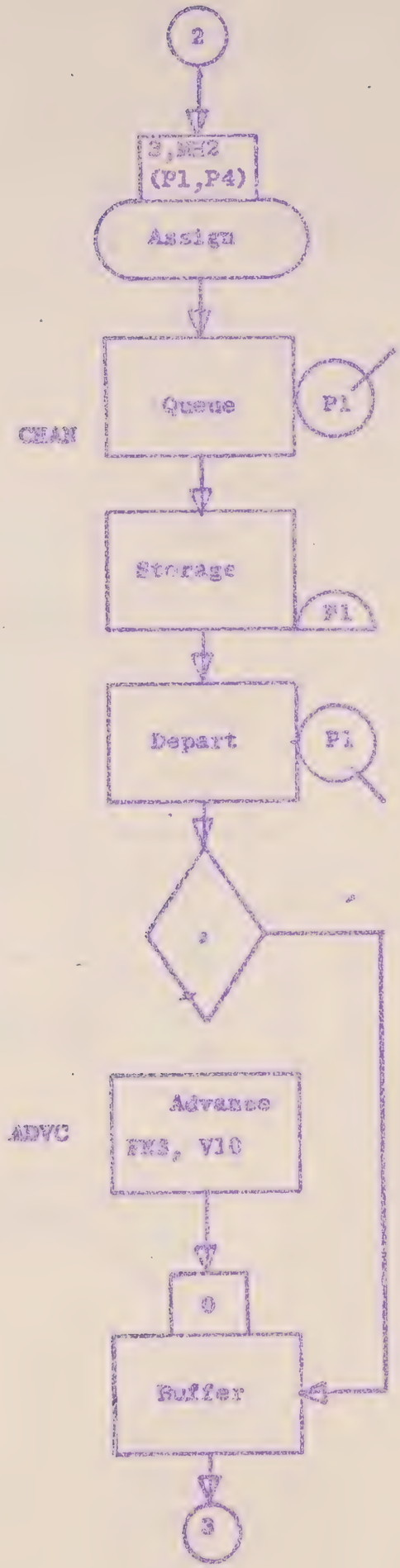
Save Packet Node Number

Begin Calculating Time Delay to Station

Assign Origin Terminal

Assign Final Destination Number

Figure A-3 (Continued)



Assign Immediate Destination Number

Begin Channels - Transmit Queue

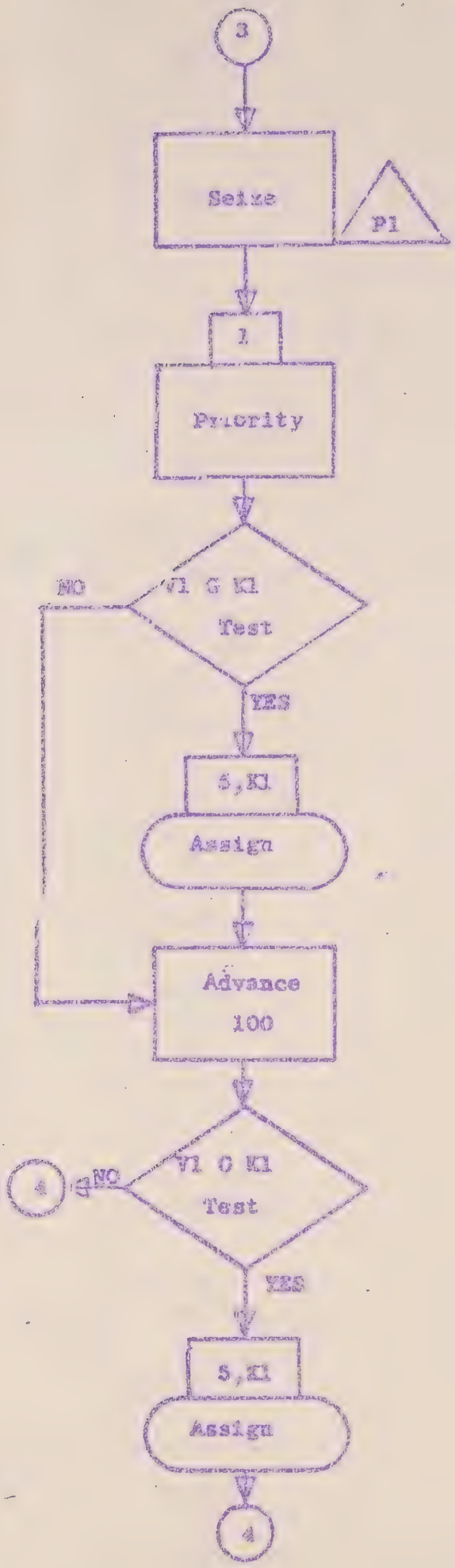
Enter Transmit Status

Leave Transmit Queue

New Packets are Transmitted

Uniformly Distributed Random Retransmission Delay

Figure A-3 (Continued)



Begin Transmission

Interference?

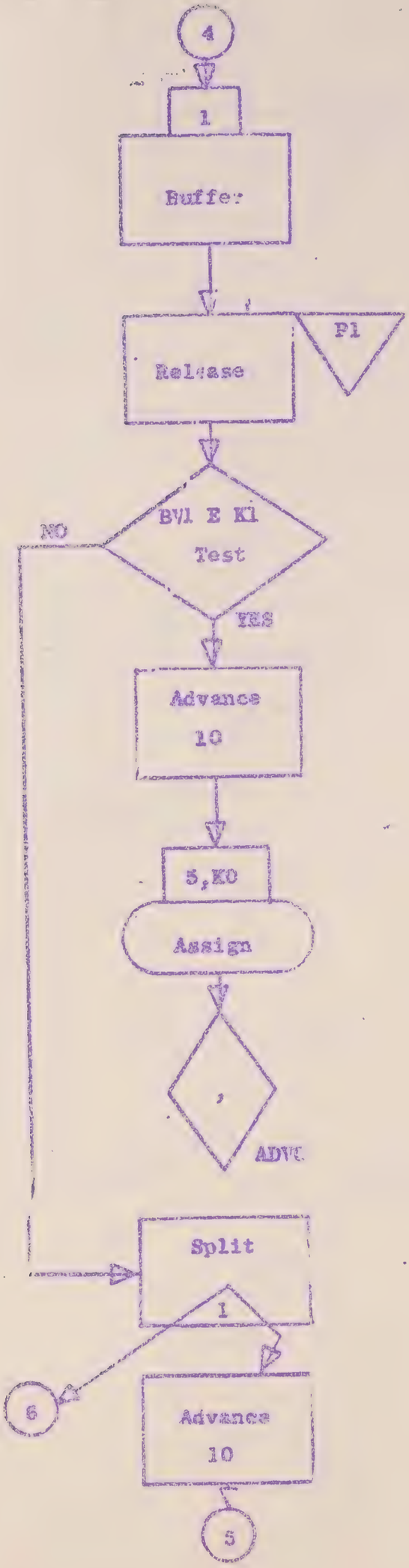
Set Interference Flag

Transmission Time

Interference?

Set Interference Flag

Figure A-3 (Continued)



Hold Until All Packets Have Been Tested for Interference at a Given Time

End of Transmission

Interference Flag Set or Buffer Capacity at Immediate Destination Filled?

Minimum Wait for Acknowledgment

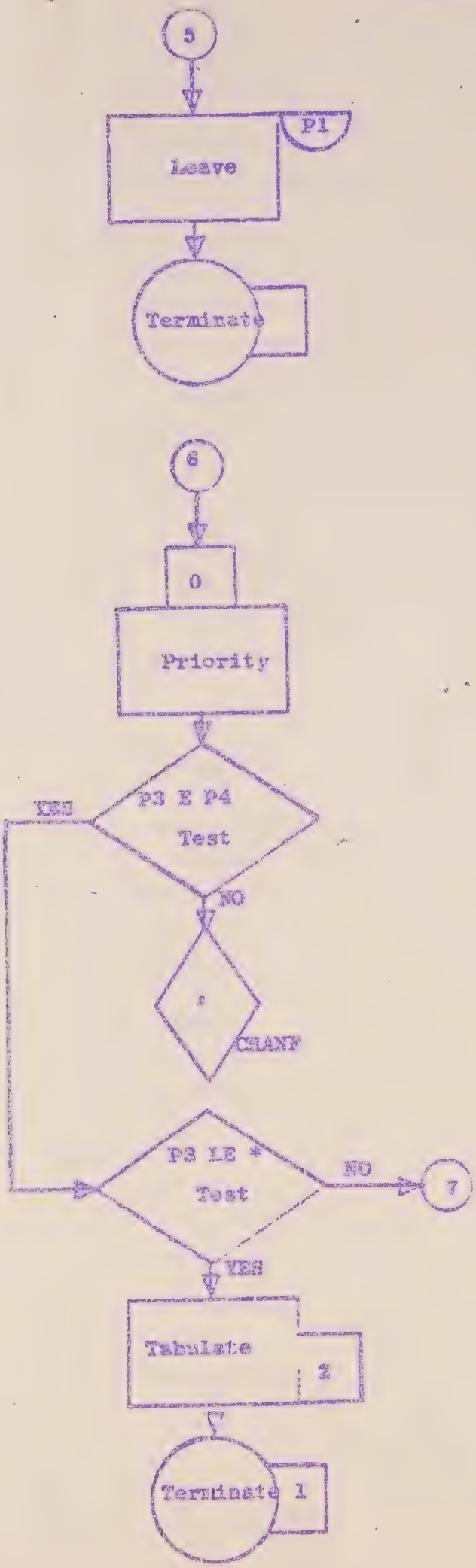
Reset Interference Flag

Transfer to Retransmission Delay

Packet Is Received at Immediate Destination (Path 6) While the Transmitter Waits for Acknowledgment

Minimum Wait for Acknowledgment

Figure A-3 (Continued)



End of Transmit Status

Remove Transmit Status Transaction

Immediate and Final Destination Equal?

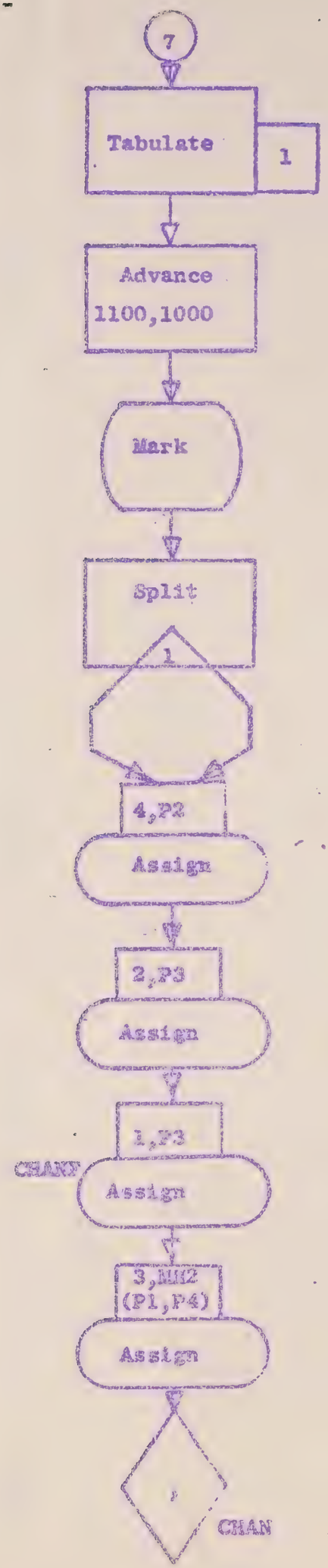
Transfer to Designate Present Location and Immediate Destination

Is the Final Destination a Terminal?
*Represents Terminal Upper Bound on the Routing Matrix - Terminals are Assigned Lowest Rows and Columns in the Matrix

Record Delay Time Station to Terminal

Remove Packet From the Network

Figure A-3 (Continued)



Record Delay from Terminal to Station

Station Processing Delay

Begin Calculating the Delay from Station to Terminal

Two Packets Returned to Terminal

Final Destination is Original Terminal

Origin is Station

Present Location is Station

Immediate Destination is Determined

Return to Channel

Figure A-4: Program Listing

```
BLOCK
NUMBER  #LOC   OPERATION  A,B,C,D,E,F,G                    COMMENTS                                  CARD NUMBER
        SIMULATE  50
*
*   GENERAL PACKET RADIO SYSTEM
*     UNSLOTTED
*
 1      FUNCTION   RN1,C24  EXPONENTIAL DISTRIBUTION
0.0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38
.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2
.97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7.0/.9997,8.0
 2      FUNCTION   P1,C2
1,11/10,11
 3      FUNCTION   P1,C4
1,4000/10,4000/10.5,1333/11,1333
 4      FUNCTION   P1,C4
1,4000/10,4000/10.5,1333/11,1333
 5      FUNCTION   P3,C3
1,1/10,1/11,500
*
 1      MATRIX     H,11,11
 2      MATRIX     H,11,11
*
        INITIAL    MH1(1-11,1-11),1/MH2(1-11,11),11
        INITIAL    MH2(11,1),1/MH2(11,2),2/MH2(11,3),3/MH2(11,4),4
        INITIAL    MH2(11,5),5/MH2(11,6),6/MH2(11,7),7/MH2(11,8),8
        INITIAL    MH2(11,9),9/MH2(11,10),10
        INITIAL    MH2(1,1),1/MH2(2,2),2/MH2(3,3),3
        INITIAL    MH2(4,4),4/MH2(5,5),5/MH2(6,6),6
        INITIAL    MH2(7,7),7/MH2(8,8),8/MH2(9,9),9/MH2(10,10),10
*
 1      VARIABLE   MH1(1,P3)*F1+MH1(2,P3)*F2+MH1(3,P3)*F3+V2
 2      VARIABLE   MH1(4,P3)*F4+MH1(5,P3)*F5+MH1(6,P3)*F6+V3
 3      VARIABLE   MH1(7,P3)*F7+MH1(8,P3)*F8+MH1(9,P3)*F9+V4
 4      VARIABLE   MH1(10,P3)*F10+MH1(11,P3)*F11
*
*
*
*
*
*
*
 10     VARIABLE   FN*
*
 1      BVARIABLE  (P5*E*K1)+(Q*3*GE*FN5*P3*E*K11)
*
 1      STORAGE    1
 2      STORAGE    1
 3      STORAGE    1
 4      STORAGE    1
 5      STORAGE    1
 6      STORAGE    1
 7      STORAGE    1
 8      STORAGE    1
 9      STORAGE    1
 10     STORAGE    1
 11     STORAGE    1
 HOLD   STORAGE    10
*
 1      TABLE      M1,100,100,50
```

```
                2       TABLE     M1,100,100,50                                    56
                *                                                                  57
1               GENERATE  ,,,,1,5                                                  58
2               ENTER     HOLD                                                     59
3               PRIORITY  0                                                        60
4               TEST L    N$INIT,K10,TERM-1                                        61
5               SAVEVALUE 2+,K1                                                    62
6               ASSIGN    1,X2                                                     63
7               TRANSFER  ,TERM                                                    64
8               ASSIGN    1,X1                                                     65
9               ADVANCE   10000,FN1                                                66
10              LEAVE     HOLD                                                     67
11              SAVEVALUE 1,P1                                                     68
12              MARK                                                               69
13              ASSIGN    2,P1                                                     70
14              ASSIGN    4,FN2                                                    71
15              ASSIGN    3,MH2(P1,P4)                                             72
16              QUEUE     P1                                                       73
17              ENTER     P1                                                       74
18              DEPART    P1                                                       75
19              TRANSFER  ,*+2                                                     76
20              ADVANCE   FN3,V10                                                  77
21              PRIORITY  0,BUFFER                                                 78
22              SEIZE     P1                                                       79
23              PRIORITY  1                                                        80
24              TEST G    V1,K1,*+3                                                81
25              ASSIGN    5,K1                                                     82
26              ADVANCE   100                                                      83
27              TEST G    V1,K1,*+2                                                84
28              ASSIGN    5,K1                                                     85
29              PRIORITY  1,BUFFER                                                 86
30              RELEASE   P1                                                       87
31              TEST E    BV1,K1,*+4                                               88
32              ADVANCE   10                                                       89
33              ASSIGN    5,K0                                                     90
34              TRANSFER  ,ADV2                                                    91
35              SPLIT     1,*+4                                                    92
36              ADVANCE   10                                                       93
37              LEAVE     P1                                                       94
38              TERMINATE                                                          95
39              PRIORITY  0                                                        96
40              TEST E    P3,P4,CHANF                                              97
41              TEST LE   P3,K10,STAT                                              98
42              TABULATE  2                                                        99
43              TERMINATE 1                                                        100
44      STAT    TABULATE  1                                                        101
45              ADVANCE   1100,1000                                                102
46              MARK                                                               103
47              SPLIT     1,THREE                                                  104
48      THREE   ASSIGN    4,P2                                                     105
49              ASSIGN    4,P3                                                     106
50      CHANF   ASSIGN    1,P3                                                     107
51              ASSIGN    3,MH2(P1,P4)                                             108
52              TRANSFER  ,CHAN                                                    109
                START     200                                                      110
                END                                                                111
```